EFFECTS OF BODY WEIGHT ON DISCRIMINATIVE-STIMULUS CONTROL BY PHENCYCLIDINE IN THE PIGEON

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Using a color-tracking procedure with responses reinforced under a second-order schedule, the discriminative-stimulus properties of phencyclidine were studied in pigeons maintained at 70%, 80%, or 90% of their free-feeding weights. The generalization curves for phencyclidine were similar at all three body weights. Generalization curves for pentobarbital, *d*-amphetamine, and saline were also unrelated to body weight. These data suggest that food deprivation may not influence the discriminative-stimulus properties of drugs in the way that it influences the reinforcing-stimulus properties of drugs. The reason may be that during discrimination training interoceptive stimuli resulting from food deprivation do not become conditioned to the stimulus properties of the drug, because the food-deprivation stimuli are paired equally often with the presence and absence of drug stimuli.

Key words: drug discrimination, drug reinforcement, food deprivation, color tracking, key peck, pigeons

Carroll and Meisch (1984) have recently reviewed a series of experiments from their laboratory demonstrating that food deprivation increases self-administration of drugs. They suggest that food deprivation enhances the reinforcing efficacy of drugs, and propose that the mechanism underlying the enhancement is based upon temporal pairing of the interoceptive stimuli produced by food deprivation and by drug. These two sets of stimuli are said to become associated through classical conditioning, although it is not entirely clear why this should occur preferentially for deprivation-related stimuli as opposed to those stimuli that accompany satiation. Carroll and Meisch also allude to the possibility that other drug actions, such as the discriminative-stimulus properties of drugs, might be affected by food deprivation as well. The present experiments were designed to assess the relationship between food deprivation and phencyclidine discrimination in the pigeon.

For a number of years we have been using

a color-tracking procedure in pigeons to study the discriminative stimulus properties of phencyclidine (McMillan, 1982; McMillan, Cole-Fullenwider, Hardwick, & Wenger, 1982; McMillan & Wenger, 1983, 1984). In the present experiments we used this procedure to study the effects of food deprivation on phencyclidine (PCP) discrimination and on the generalization of the phencyclidine discriminative stimulus to other doses of PCP and to doses of pentobarbital and *d*-amphetamine in the pigeon. Because Carroll and Meisch (1980) have suggested that reduced body weight is a more powerful determinant of oral PCP self-administration than is the temporal availability of food, we determined our dose-effect curves in pigeons maintained at 70%, 80%, or 90% of their free-feeding weights.

METHOD

Subjects

Four of the 5 male White Carneaux pigeons used in previous experiments in this series on phencyclidine discrimination (McMillan, 1982; McMillan et al., 1982; McMillan & Wenger, 1983, 1984) were used. The birds were housed in a temperature- and humidity-controlled room that was lighted from 7:00 AM to 7:00 PM. With free access to food and water, the birds weighed 589 to 703 g; they had been maintained at 80% of

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their free-feeding weights in previous experiments and were at the 80% weights at the beginning of the current experiments.

Apparatus

The experimental chamber was a Gerbrands Model G7313 pigeon test cage equipped with a Gerbrands feeder and three response keys, each of which could be trans-illuminated with several colors by a Gerbrands 28-V dc Key Light Assembly containing two 0.04-W bulbs for each key color. The chamber was enclosed inside a Gerbrands Model G7211 sound- and light-attenuating enclosure. The minimum force required to operate each key was 0.05 N. A relay mounted inside the chamber operated whenever the contacts on a side key were opened. Two 28-V dc houselights illuminated the experimental chamber during the session except during a food cycle. A TRS-80®, Model III (Radio Shack) computer, located in a separate room adjacent to the room containing the experimental chamber, controlled the schedule and recorded the data.

Procedure

The training of these pigeons has been discussed in detail previously (McMillan et al., 1982). The schedule in effect at the beginning of these experiments began with white illumination of the center key. A peck on that key extinguished it and lighted the two side keys, one with a red light and one with a green light. Five responses on either side key (fixed-ratio, or FR-5 component) extinguished both side-key lights, reset the ratios on the side key to 5, and relighted the center key to reinstate the original condition. Food (8-s access to grain) was presented only after 10 FR-5 components had been completed on the "correct" side key. Using the terminology of Kelleher (1966) for second-order schedules, this schedule is referred to as FR 10 (FR 5). If 1.5 mg/kg phencyclidine had been administered before the session, pecks on the red key were defined as correct and produced food under the FR 10 (FR 5) schedule. If saline had been administered before the session, pecks on the green key were defined as correct. Five pecks on the key not defined as correct relighted the center key but did not decrease the number of FR 5s required on the correct key for food delivery. Position of the red and green colors

of the side keys varied randomly after each center-key response. The session (on training days) terminated after food presentation had occurred six times, or after 600 s, whichever occurred first. Sessions were conducted Monday through Friday.

During the first 3 or 4 days of the week, the pigeons were given saline or 1.5 mg/kg PCP 10 min before the session (training session). If a pigeon completed no more than four FR 5s on the incorrect key prior to the first food delivery following both a PCP and a saline training session, the bird qualified for determination of cumulative dose-effect curves. On Thursday or Friday, cumulative dose-effect curves (McMillan et al., 1982) were determined to measure generalization from the training dose of PCP to other doses of PCP, pentobarbital, *d*-amphetamine, or saline. To summarize briefly, a bird was injected intramuscularly and placed into the chamber. After 10 min, the session was initiated and it was terminated with the first food delivery. Food was delivered upon the completion of 10 FR 5s on either the red or the green key, whichever occurred first. Immediately after food delivery, the bird was removed from the chamber and given a second injection and the process was repeated. Repetitions of the procedure continued until a cumulative dose was reached that disrupted responding such that the bird did not obtain food within 600 s, or until a predetermined maximum cumulative dose of drug was reached (1.7 mg/kg PCP, 17.0 mg/kg pentobarbital, or 3 mg/kg *d*-amphetamine). All doses shown in the figures are cumulative doses (the sum of all doses given to the bird during that session). Drugs were administered and doses were calculated as follows: Phencyclidine hydrochloride, sodium pentobarbital, or *d*-amphetamine sulfate was dissolved in 0.9% saline and administered in a volume of 0.1 mL/100 g of body weight. A cumulative saline curve (four injections under the same conditions as with the drugs) was determined the week before cumulative dosing began, and again the week after cumulative dosing terminated.

Discrimination data prior to the first food delivery of a session were plotted as a percentage of responses on the red key (hereafter referred to as the PCP key). The average latency to respond on the center key and average rate of responding on the side keys also were

assessed. Occasionally birds made fewer than five responses on one side key before making five responses on the other. These "extra" responses were also plotted.

Body weight was manipulated as follows: The pigeons were stabilized at 80% of their free-feeding weights for 4 weeks, after which cumulative dosing with saline, PCP, pentobarbital, *d*-amphetamine, and saline was performed over a 5-week period. A single cumulative dose-effect curve was determined for each bird under these five conditions. Subsequently, the body weights of 2 birds (58 and 62) were increased to 90% and those of the other 2 birds (60 and 59) were decreased to 70% of free-feeding weights. After 4 weeks of training, the same cumulative-dosing experiments were performed over a 5-week period. Next, the body weights of the birds at 70% were increased to 90% of free-feeding weights, and those of 90% were decreased to 70%. After 4 weeks of training at the new body weights, the same cumulative-dosing experiments were performed over a 5-week period.

RESULTS

The effects of cumulative saline administration are shown in Figure 1. Although Bird 62 responded somewhat more frequently on the PCP-correlated key color (red) than did the other birds during cumulative saline dosing, none of the birds showed much tendency to respond on the PCP key during that procedure. Changes in body weight did not produce any systematic effect on stimulus control during cumulative saline administration. Values on the *x* axis indicate the ordinal number of an injection within a cumulative-dosing session.

Figure 2 shows the effects of cumulative dosing with PCP for individual birds at each body weight. Although for 3 of the 4 birds responding on the PCP key occurred to a lesser extent after 1.0 mg/kg PCP when the body weight was 80% of the free-feeding weight than at the other body weights, this effect does not hold across doses. In general, there was no systematic relationship between body weight and the PCP generalization curve.

Figure 3 shows the birds' pentobarbital generalization curves of the birds trained to discriminate PCP from saline, for the different body weights. Although there was a considerable

degree of generalization from PCP to pentobarbital in all birds except Pigeon 59, the shape of the generalization curve did not depend on the birds' body weights. There is no obvious explanation for the dip in the generalization curve following 10 mg/kg pentobarbital in Bird 60, but it was consistently observed at all three body weights for this bird.

When cumulative doses of *d*-amphetamine were administered, Birds 59 and 60 never responded on the PCP key after any dose at any body weight (Figure 4). Birds 58 and 62 responded on the PCP key to about the same extent as they did during cumulative saline administration.

Table 1 presents latencies to respond on the center key and rates of responding on the side keys for the saline condition and for all drug conditions. In general, under nondrug conditions, latency increased and mean rate of responding decreased as the body weight increased. *d*-Amphetamine enhanced the effect of body weight on latency and rate of responding to a greater extent than did PCP, whereas pentobarbital had a clear effect of this type only in Bird 59.

Occasionally birds made one to four responses on one side key before completing five responses on the other key. These "extra" responses entered into the calculation of percentage of responses on the PCP key, but had no other programmed consequences. Figure 5 shows these "extra" responses in individual birds under all conditions of the experiment. During the majority of sessions, no such extra responses occurred, and in only two instances (after 17.5 mg/kg pentobarbital to Pigeon 60 at 80% of ad-lib weight and after 1.7 mg/kg *d*-amphetamine to Bird 58 at 90% of ad-lib weight) did more than four such responses occur during a session. With the possible exception of a suppression of "extra" responses by *d*-amphetamine when the birds were at 70% of ad-lib weights, "extra" responses did not appear to be dose dependent or drug dependent.

DISCUSSION

Body weight did not seem to be an important determinant of the discriminative-stimulus properties of phencyclidine, or in the generalization of the stimulus properties of the training dose of PCP to other doses of PCP

Fig. 1. Cumulative saline curves in pigeons maintained at 70% (□), 80% (○), and 90% (Δ) of free-feeding weights. Abscissa: consecutive (within-session) saline injections. Ordinate: percentage of responses on the key correlated with PCP. Each point represents a mean of two observations for a given pigeon trained to discriminate 1.5 mg/kg PCP from saline.

Fig. 3. Cumulative dose-effect curves for pentobarbital in pigeons maintained at 70% (□), 80% (○), and 90% (Δ) of free-feeding weights. Abscissa: mg/kg dose of sodium pentobarbital, log scale. Ordinate: percentage of responses on the key that had been correlated with PCP. Each point represents a single assay for 1 pigeon trained to discriminate 1.5 mg/kg PCP for saline.

Fig. 2. Cumulative dose-effect curves showing discrimination of PCP in pigeons maintained at 70% (□), 80% (○), and 90% (Δ) of free-feeding weights. Abscissa: mg/kg dose of phencyclidine hydrochloride, log scale. Ordinate: percentage of responses on the key correlated with PCP. Each point represents a single assay for 1 pigeon trained to discriminate 1.5 mg/kg PCP from saline.

Fig. 4. Cumulative dose-effect curves for *d*-amphetamine in pigeons maintained at 70% (□), 80% (○), and 90% (Δ) of free-feeding weights. Abscissa: mg/kg dose of *d*-amphetamine sulfate, log scale. Ordinate: percentage of responses on the key that had been correlated with PCP. Each point represents a single assay for 1 pigeon trained to discriminate 1.5 mg/kg PCP from saline.

Table 1

Mean latency (seconds) to respond on the center key and rate of responding (responses per second) on the side keys after saline or drug administration, of pigeons at different body weights. Values for saline are the range of latencies and response rates for the eight saline injections (two cumulative curves with four injections per curve). All other assays are single determinations for 1 animal. A—indicates that no responses occurred.

Condition	Dose	Latency (seconds)				Rate (responses/second)			
		Bird				Bird			
		58	59	60	62	58	59	60	62
Saline range		1.53	0.98	1.83	1.04	1.45	2.02	1.37	1.20
at 70%		5.77	1.51	3.85	3.11	2.61	2.56	2.29	1.85
Saline range		2.05	1.80	1.46	0.98	1.51	1.16	0.27	0.72
at 80%		9.74	36.70	15.29	2.48	2.52	1.93	1.92	1.99
Saline range		4.08	1.14	2.05	1.14	0.37	0.84	0.08	1.13
at 90%		78.91	19.21	—	2.96	2.55	1.77	1.73	1.58
PCP at	0.30	1.24	1.76	2.85	2.52	2.29	1.29	0.67	1.20
70%	0.56	1.49	3.07	4.25	1.88	2.63	1.57	0.66	1.08
	1.00	2.19	7.44	20.14	2.33	1.69	1.31	1.54	0.86
	1.70	1.86	—	13.42	3.19	1.89	—	1.10	1.26
PCP at	0.30	4.43	2.21	4.73	1.33	2.27	0.74	1.45	0.73
80%	0.56	4.21	5.05	2.99	1.63	2.47	1.89	0.91	1.34
	1.00	10.33	3.33	6.94	1.61	2.01	1.56	1.42	2.07
	1.70	—	—	17.55	19.69	—	—	0.18	0.22
PCP at	0.30	16.97	1.48	—	1.46	2.14	0.70	—	0.28
90%	0.56	28.19	5.25	17.61	1.45	1.92	0.11	0.20	1.61
	1.00	4.05	—	—	1.15	0.68	—	—	1.47
	1.70	—	—	—	66.90	—	—	—	0.06
Pentobarbital	3.00	0.99	1.02	3.19	1.14	2.49	2.19	0.74	1.61
at 70%	5.60	1.31	1.24	1.68	1.13	2.86	1.97	1.73	2.20
	10.00	1.90	1.01	1.80	1.06	2.58	2.24	1.82	1.59
	17.00	4.91	9.60	9.22	1.74	1.26	0.27	0.24	1.51
Pentobarbital	3.00	3.01	1.51	2.81	1.19	2.08	1.44	0.61	1.46
at 80%	5.60	1.30	2.36	3.47	0.97	2.74	1.30	1.78	1.73
	10.00	1.30	1.75	1.19	0.98	2.61	1.26	1.89	1.82
	17.00	17.30	3.00	17.89	1.16	0.74	0.92	0.28	1.44
Pentobarbital	3.00	7.19	3.42	4.07	1.66	0.40	1.23	1.19	0.88
at 90%	5.60	13.90	2.86	4.63	1.36	2.03	0.76	1.84	1.48
	10.00	1.65	—	13.22	1.02	2.45	—	1.94	2.03
	17.00	9.98	—	10.50	1.02	1.68	—	0.90	1.58
<i>d</i> -Amphetamine	0.30	1.40	1.24	1.94	1.34	2.32	2.37	1.34	1.22
at 70%	1.00	1.13	1.64	2.81	1.01	1.95	1.89	1.41	1.45
	1.70	2.84	3.26	17.74	1.09	1.66	1.95	1.51	1.75
	3.00	4.04	—	—	1.26	0.96	—	—	1.28
<i>d</i> -Amphetamine	0.30	20.33	3.10	8.43	2.10	1.95	0.51	0.92	0.40
at 80%	1.00	5.07	42.11	—	1.31	2.11	0.44	—	1.92
	1.70	3.00	—	—	1.30	1.33	—	—	1.69
	3.00	13.40	—	—	—	0.19	—	—	—
<i>d</i> -Amphetamine	0.30	9.27	—	86.80	1.57	0.73	—	0.74	0.75
at 90%	1.00	5.08	—	—	1.54	2.32	—	—	0.44
	1.70	28.01	—	—	—	0.04	—	—	—
	3.00	21.50	—	—	—	0.01	—	—	—

or to other drugs. Such data suggest that the discriminative-stimulus properties of drugs, unlike their reinforcing-stimulus properties (Carroll & Meisch, 1984), are not enhanced by food deprivation. "Enhancement" of stim-

ulus control might be reflected by a shift in dose-effect curves to the left with decreasing body weight (stimulus control by lower doses of phencyclidine), or by a more abrupt shift from responding on the saline key to respond-

Fig. 5. "Extra" responses (those that did not complete an FR 5, see Method) following saline or drugs in pigeons at 70% (column 1), 80% (column 2), or 90% (column 3) of ad-lib body weights. Abscissa: dose, log scale (four consecutive saline administrations indicated in the top row of frames). Ordinate: total number of extra responses that occurred prior to food delivery during cumulative dosing. Symbols are as follows: ●, Bird 62; ○, Bird 59; ▲, Bird 60; △, Bird 58.

ing on the PCP key as the phencyclidine dose increases (more complete control by presence or absence of the drug stimulus). Neither of these effects was observed.

In studying the discriminative-stimulus properties or the reinforcing properties of drugs, the assumption is usually made that the drug produces interoceptive stimuli that control an animal's responses. In the case of a drug as reinforcing stimulus, these interoceptive stimuli maintain the behavior that leads to their occurrence, whereas when the drug functions as a discriminative stimulus, its discriminative-stimulus properties must be es-

tablished by differential reinforcement. Clearly many drugs can function simultaneously as discriminative stimuli and as reinforcing stimuli, and PCP is such a drug. In such cases, the interoceptive discriminative stimuli and the interoceptive reinforcing stimuli produced by the drug may overlap, or perhaps even be identical. This possibility might lead one to predict that operations such as food deprivation, which affect behavior reinforced by the stimulus properties of a drug, might also affect the discriminative-stimulus properties of that drug. The present experiments do not provide any evidence that this occurs.

Carroll and Meisch (1984) have suggested that the reinforcing properties of drugs are enhanced by food deprivation because the interoceptive stimuli produced by food deprivation are paired with the reinforcing interoceptive stimuli produced by drug, and thereby the deprivation stimuli become conditioned stimuli for drug-seeking responses; however, it is not clear why a similar pairing of interoceptive stimuli correlated with satiation do not function in a similar manner. In the case of the discriminative-stimulus properties of drugs, interoceptive drug stimuli attain their function as discriminative stimuli through differential reinforcement. Although different responses are reinforced in the presence or absence of interoceptive drug stimuli during discrimination training, both types of responding (e.g., green-key responses vs. red-key responses) are paired equally often with the interoceptive stimuli produced by food deprivation during training; thus there is no basis for the discriminative stimuli to be strengthened differentially during food deprivation.

Food deprivation did not affect the degree to which the PCP stimulus generalized to other drugs. At all body weights, responding on the PCP key failed to occur more than occasionally after *d*-amphetamine was administered, and the generalization curves for pentobarbital were similar at all body weights. As in the case with the phencyclidine generalization curve, food deprivation would not be expected to affect generalization from PCP to other drugs because there was no opportunity for the interoceptive stimuli correlated with food deprivation to become associated with the differential reinforcement of responses in the presence of interoceptive stimuli produced by drug states.

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